MEMBRANE BASED THERMAL CONTROL DEVELOPMENT

NASW-97015

INTERIM REPORT

DATE ISSUED
SEPTEMBER 1997

PREPARED BY
UNITED TECHNOLOGIES CORPORATION
HAMILTON STANDARD SPACE
SYSTEMS INTERNATIONAL, INC.
WINDSOR LOCKS, CONNECTICUT 06096

Prepared By: Karen Murdoch
Karen Murdoch
Principal Investigator

Approved By: Mark A. Shurley
Charles Beal
Program Manager

Table of Contents

Section **Page**

1.0 Introduction

This report summarizes the work completed thus far of the subject contract, Membrane Based Thermal Control Development, NASW-97015. This contract involves the investigation of the feasibility of using a membrane device as a water boiler for thermal control. The membrane device permits water vapor to escape to the vacuum of space but prevents the loss of liquid water. The vaporization of the water provides cooling to the water loop. This type of cooling device would have application for various types of short duration cooling needs where expenditure of water is allowed and a low pressure source is available such as in space or on a planet's surface.

A variety of membrane samples, both hydrophilic and hydrophobic, were purchased to test for this thermal control application. An initial screening test determined if the membrane could pose a sufficient barrier to maintain water against vacuum. Further testing compared the heat transfer performance of those membranes that passed the screening test.

2.0 Summary

Different membrane materials, 17 hydrophilic and 9 hydrophobic were screened. The screening test consisted of introducing water to the membrane surface and observing how much, if any, water wept through the membrane at differential pressures up to 15 psid. Of these 26 different types, 12 samples passed the screening test and were performance tested.

Performance testing consisted of measuring the rate of water evaporating through the membrane; water flowed past the surface of one side of the membrane with the other side exposed to vacuum. Temperature measurement of the water stream in and out of the membrane device indicated the rate of heat transfer provided by the membrane. This value was correlated to a measurement of the amount of water lost from the water supply.

Overall, the hydrophilic membranes had a higher heat transfer rate than the hydrophobic membranes. The two membranes that performed the best in this set of performance testing were the V-180, hydrophilicized PVDF, made by Millipore and the polyacrylonitrile made by FPI Separations. These membranes will be subjected to the next set of endurance and contamination testing. Meanwhile, other membrane materials and pore sizes will be investigated.

3.0 Discussion

3.1 Membrane Selection

Various membrane vendors were surveyed to find potential candidates that would meet the requirements of the test program. There is quite a variety of commercially available membranes in both flat sheet and hollow fiber form. Table 3-I lists all of the membranes tested and some of their physical characteristics.

Table 3-I Membrane Samples Tested

Trade Name	Manufacturer	Material	Pore Size	Screen Test
Hydrophilic Membranes				
Pall 0.02	Pall	PVDF	0.02 um	PASS
V-180	Millipore	PVDF	0.2 um	PASS
Nafion 105	DuPont	perfluorinated tetrafluoroethylene	N/A	PASS
GFT Pervaporation	GFT	proprietary	N/A	PASS
Supor 450	Gelman	polyethersulfone	0.45 um	FAIL
Millipore 1.2 RA	Millipore	mixed cellulose esters	1.2 um	FAIL
MF-Millipore (VSWP)	Millipore	mixed cellulose esters	0.025 um	PASS
Durapore (VVLP)	Millipore	PVDF	0.10 um	PASS
H1-P10-43	Amicon	polysulfone tubes	10K NMWC	FAIL
H1M-P01-43	Amicon	polysulfone tubes	0.1 um	FAIL
MF-Millipore (VCWP)	Millipore	mixed cellulose esters	0.10 um	PASS
MF-Millipore (SCWP)	Millipore	mixed cellulose esters	8.0 um	FAIL
UMD-030-PES	FPI Separations	polyethersulfone	30K NMWC	PASS
UMD-030-PAN	FPI Separations	polyacrylonitrile	30K NMWC	PASS
UMS-500-PES	FPI Separations	polyethersulfone	500K NMWC	FAIL
Versapore 10000T wo/wa	Gelman	acrylic copolymer	10 um	FAIL
Versapore 200 w/wa	Gelman	acrylic copolymer	0.2 um	FAIL
Hydrophobic Membranes				
Cell Guard	Hoecht Celanese	polypropylene / polyethylene	0.04 um	PASS
Pall 0.02 um Hydrophobic	Pall	proprietary	0.02 um	PASS
Gore-Tex 10-15	Gore	PTFE	N/A	FAIL
Goretex 5 Polyester	Gore	PTFE	N/A	FAIL
Goretex x11475	Gore	PTFE	N/A	PASS
Mitex	Millipore	PTFE	10.0 um	FAIL
Fluoropore	Millipore	PTFE	3.0 um	FAIL
Fluoropore	Millipore	PTFE	1.0 um	FAIL
Mitex	Millipore	PTFE	5.0 um	FAIL

NMWC - nominal molecular weight cutoff
N/A - not available
PVDF - polyvinylidene fluoride

A characteristic of all membrane materials is it wettability. Typically, a material is either hydrophilic (attracts water) and wets evenly or it is hydrophobic (repels water) and causes water to bead on the surface.

In this application a hydrophilic membrane would wet evenly through the thickness of the membrane. The low pressure of the vacuum source would cause the water to freeze and sublime at the surface. This is the same phenomenon that occurs in the metal sublimator currently used in the EMU.

A hydrophobic membrane will not wet and only the vaporized water molecules can pass through the pores of the membrane.

Figures 3-1 and 3-2 depict the water evaporation phenomena of the two material types.

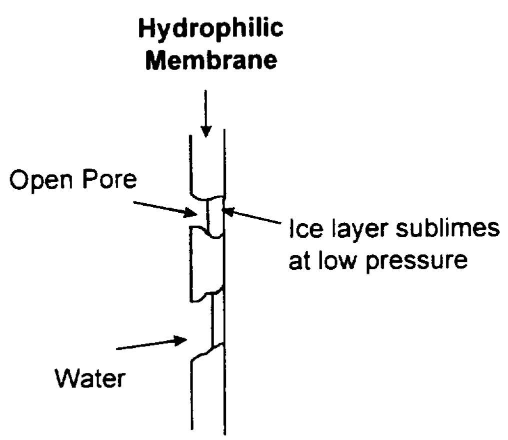


Figure 3-1 Water Evaporation Through Hydrophilic Membrane

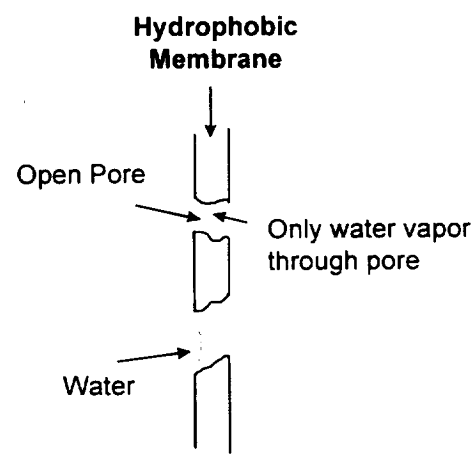


Figure 3-2 Water Evaporation Through Hydrophobic Membrane

The candidate membranes listed in Table 3-I are categorized as either hydrophilic or hydrophobic.

Hydrophilic material types tested include polyvinylidene fluoride (PVDF), perfluorinated tetrafluoroethylene, polyethersulfone, mixed cellulose esters, polyacrylonitrile, acrylic copolymer and a proprietary hydrophilic material.

Hydrophobic materials tested include polytetrafluoroetyhlene (PTFE), polypropylene/ polyethylene, and a proprietary hydrophobic material.

3.2 Test Apparatus and Procedures

3.2.1 Membrane Support Fixture

A membrane support fixture, designed by HSSSI, is used for both the screening tests and the performance tests. The fixture is shown in Figure 3-3. It consists of a back and front that sandwich the flat sheet membranes. The back piece has an inlet and exit manifold that permits water to circulate through a 3" dia x .25 in deep cavity and in direct contact with the back of the membrane. The front of the fixture has a perforated plate that supports the membrane against the differential pressure applied. Both the front and the back of the fixture have o-seals to prevent water leakage directly to vacuum.

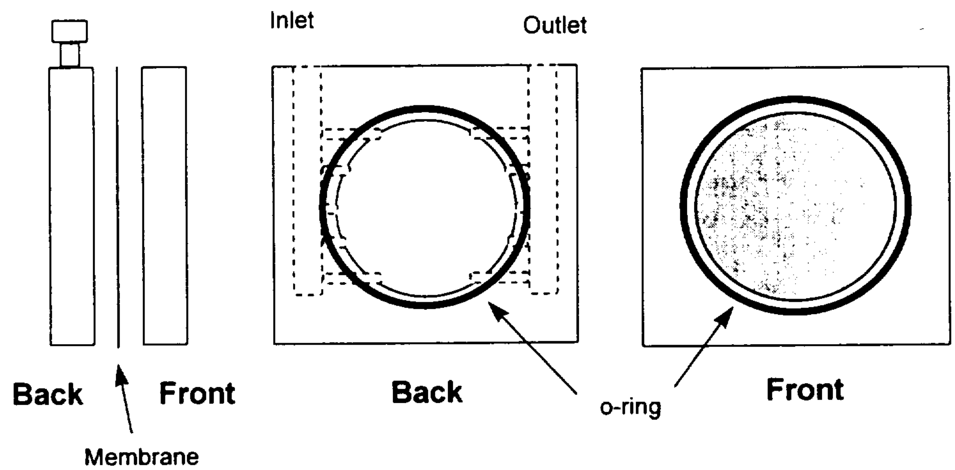


Figure 3-3 Membrane Support Fixture

3.2.2 Screening Test

A qualitative test determined each of the membrane samples' ability to hold back liquid water. Samples that did not pass this screening test were not further tested in the vacuum chamber. Figure 3-4 shows the apparatus used for this test. It consists of a water filled tank pressurized with nitrogen and the membrane support fixture. The water stand pipe of the tank connects to the inlet of the membrane support fixture. A small amount of pressure applied to the tank forces water to flow out of the stand pipe. Once enough water filled the membrane support fixture to displace all of the air, the outlet of the fixture was capped.

The nitrogen slowly pressurized the tank to a maximum of 15 psig. The surface of the exposed membrane was observed to see how much water, if any, wept through the membrane. Those membranes that showed little or no water seepage were further tested in the vacuum chamber. Table 3-I lists the membranes that did and did not pass the screening test.

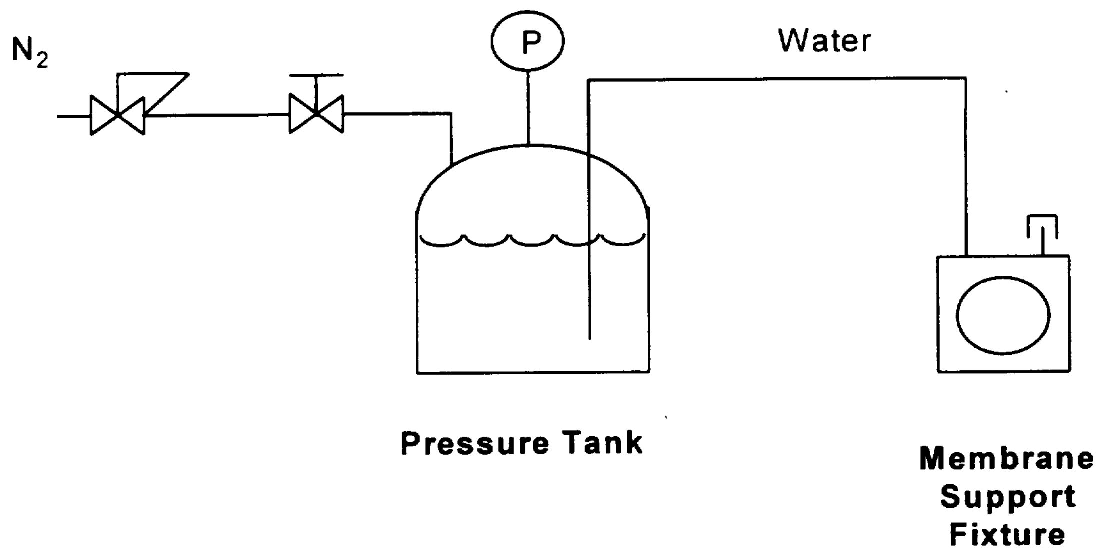


Figure 3-4 Screening Test Set-up

3.2.3 Performance Test

The next level of performance testing involved measuring the evaporation of water in a vacuum. The test rig used for this process is shown schematically in Figure 3-5.

A gear pump circulates the water and the flow rate is controlled by a variable area flow tube with a needle valve. The water flows in and out of a reservoir with a burette attached at the top. This provides make up water to replace the amount that evaporates. The water also flows through a heat exchanger in a constant temperature bath. This arrangement allows the nominal system temperature to be set. Shut off valves are located at the inlet and outlet of the membrane support fixture to enable removal of the fixture from the test rig. Thermocouples measure the temperature of the water at the inlet and outlet of the membrane support fixture. The membrane support fixture is suspended in a vacuum chamber. A liquid nitrogen cold trap prevents water vapor from reaching the vacuum pump. The vacuum chamber pressure can be controlled as low as 0.1 Torr by adjusting a needle valve to allow air to bleed into the vacuum pump inlet.

WME Test Facility Schematic

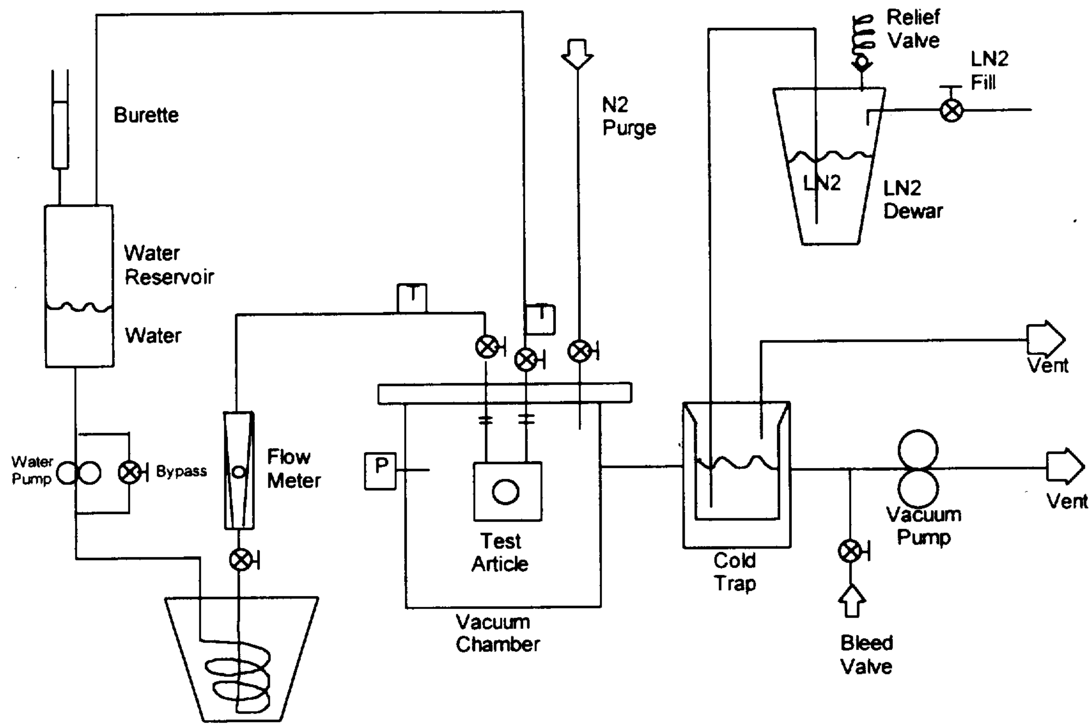


Figure 3-5 Performance Test Set-up

The membrane is installed in the support fixture which is then installed into the vacuum chamber. The vacuum pump is started and the chamber pressure is lowered prior to opening the water flow valves. There is usually some residual water in the test fixture from the screening test that will freeze and sublime as the pressure drops. There is a bypass leg on the pump to prevent deadheading when the pump is activated with the shutoff valves closed. Once the pressure in the vacuum chamber is stabilized, the water shutoff valves are slowly opened to allow water to flow to the membrane surface.

The inlet and outlet water temperatures are measured along with the water flow rate to calculate the heat transfer through the membrane device. This calculation is verified by measuring the amount of water used from the burette over a length of time.

3.3 Results

All of the membranes that were tested in the vacuum chamber are listed in Figure 3-6. The heat transfer rate of the membranes, given in W/m^2, are for 21 C inlet temperature and 0.5 l/min flow rate.

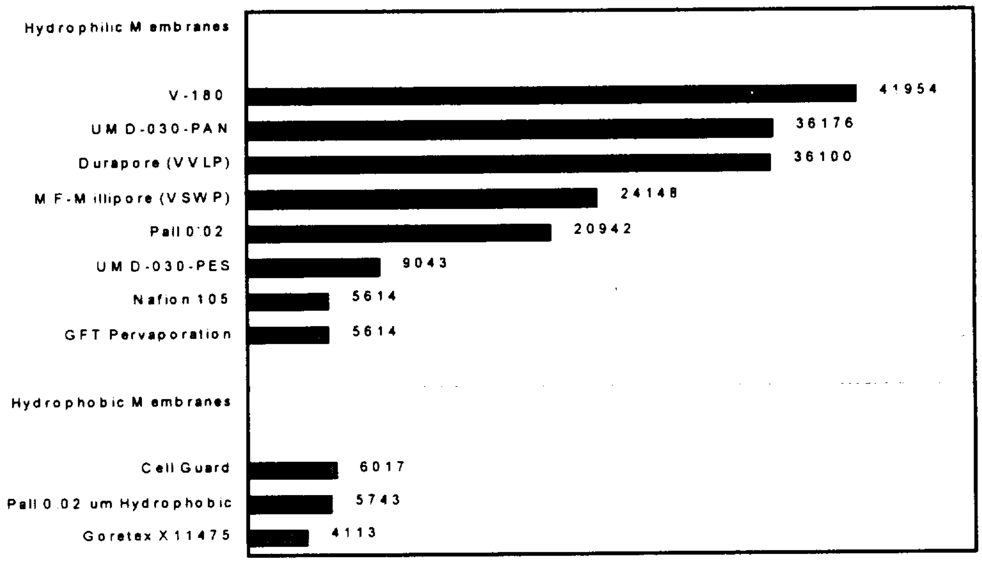


Figure 3-6 Heat Transfer Rates of Selected Membranes

The hydrophilic membranes exhibited heat transfer rates considerably higher than the hydrophobic membranes. The heat transfer rates of the hydrophilic membranes recorded in Figure 3-6 approach the 44,000 W/m^2 nominal heat transfer rate required by the EMU.

Two of the membranes, one hydrophilic and one hydrophobic, were tested under varying flow and temperature conditions. Figures 3-7 and 3-8 show the effects of these operating conditions. The heat transfer rate is more strongly affected by inlet temperature than flow rate. It appears from the data that there is a limiting flow rate after which the rate will no longer increase.

Figure 3-7

Temperature Effect on Heat Transfer

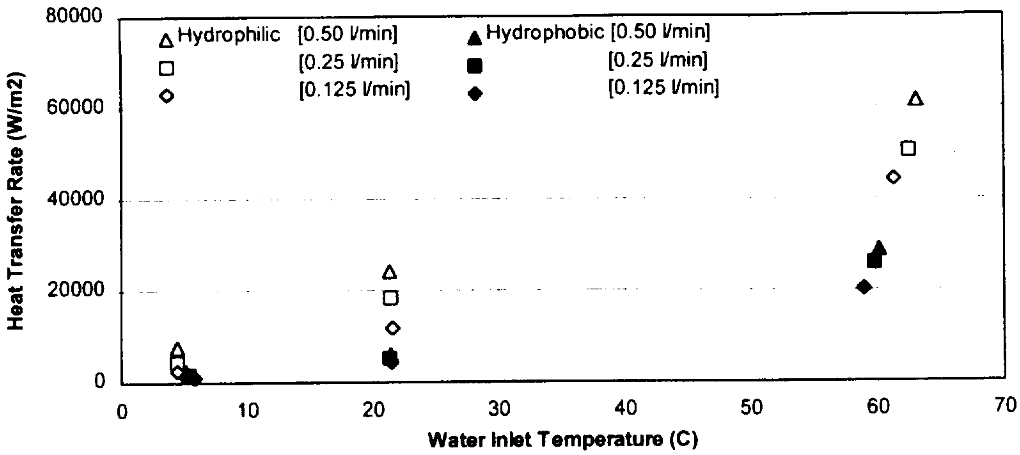
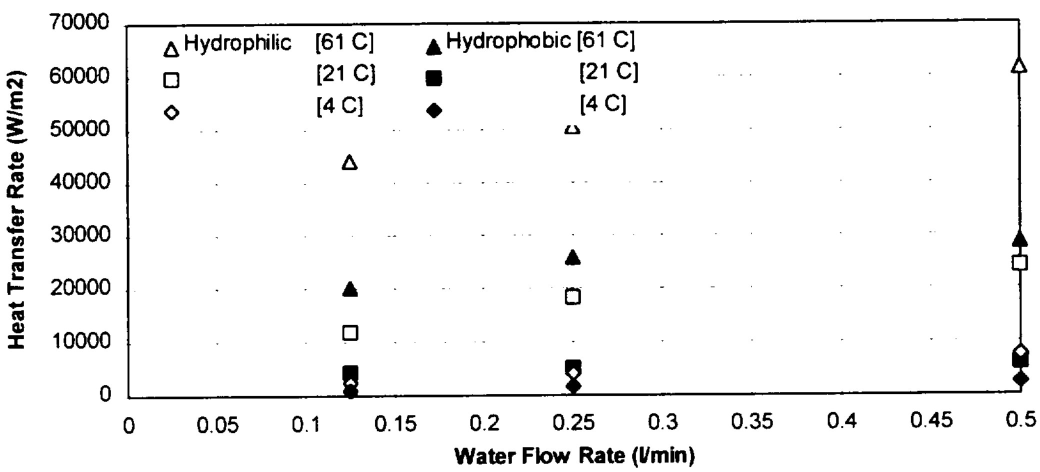


Figure 3-8

Flow Effect on Heat Transfer



4.0 Conclusion

Testing showed that hydrophilic membranes in general have a higher water transport rate, and therefore higher heat transfer rate, than hydrophobic membranes. Hydrophilic membranes with small pore sizes are capable of withstanding the pressure differential imposed on them without leaking liquid water through. The best membrane material tested to date approaches the heat transfer performance of the current metal sublimator of 44 kW/m^2 (14 $kBTU/hr\text{-}ft^2$).

5.0 Recommendations

We recommend continuing with the test plan as proposed. The next task item in the plan for this contract is to determine the performance of a selected membrane over a wide range of temperature and flow conditions. This will include testing at more than three temperatures to get a better understanding of the temperature affect. Also, the affect of flow rate should be investigated further to determine the point at which the heat transfer is maximized.

After the operating envelope is determined, the membrane should be endurance tested. Endurance testing would include baseline performance over a duration of 8 hours or more, followed by testing with contaminated water for the same amount of time.

Another recommended test is to subject the membrane to periodic freezing and thawing, either static or dynamic. Static testing would entail taking the membrane in the test fixture and placing it in a freezer. Dynamic testing would mean lowering the flow to the membrane so that very little heat is available thus freezing the water in and around the membrane.

Additional membrane samples may be tested as they become available to compare with the performance of the materials tested to date.

Appendix

WME TEST DATA RESULTS

<==== ==== RAW DATA ==== ===>

MEMBRANE DESCRIPTION	WATER FLOW RATE LPM	WATER INLET TEMP F	WATER OUTLET TEMP F	TEST PRESS TORR	WATER USED ML	TIME MIN	TEMP DIFF F	WEIGHT FLOW water Lb/Hr	HEAT FLOW mcdT Btu/Hr	water HEAT vhv Btu/Hr	Average Calculated Heat BTU/Hr	Average Specific Flux Btu/Hr/Ft2
PALL 0.02 PHILLIC	1	74.8	71.5	0.68			3.3	132.0	435.4		435	19583
	1	82.8	79.4	0.71			3.4	131.8	448.2		448	20155
	0.5	88	81.1	0.68			6.9	65.9	454.5		455	20441
4/10/97	0.5	94	86.8	0.67			7.2	65.8	473.9		474	21311
	1	93.4	88.6	0.74			4.8	131.6	631.8		632	28412
	1	93.2	88.4	0.78			4.8	131.6	631.8		632	28413
	1.86	91.3	88.2	1			3.1	244.9	759.1		759	34137
					180	40				647		
CELL GUARD	1	95.2	94.2				1	131.5	131.5		132	5916
PHOBIC	0.5	98.9	97				1.9	65.7	124.9		125	5617
4/7/97	0.5	100.4	98.5				1.9	65.7	124.9		125	5615
PALL .02UM PHOBIC	0.5	102.4	101.2	0.58			1.2	65.7	78.8		79	3545
4/10/97	1	101.7	101.2	0.58			0.5	131.4	65.7		66	2954
	0.25	105.1	102.6	0.98			2.5	32.8	82.1		82	3691
	0.25	104.6	102.4	0.98			2.2	32.8	72.2		72	3248
Millipore Hydrophillic	1	87.6	82.9	1			4.7	131.7	619.2		619	27845
HUM-10 membrane	1	90.8	85.3	0.95			5.5	131.7	724.3		724	32571
shiny side in 4/11/97					200	13.4				2145		
NAFION 105	0.5	73.2	72.5	0.48			0.7	66.0	46.2		46	2077
4/15/97	0.5	70.8	70.2	0.46			0.6	66.0	39.6		40	1781
	0.5	69.5	69	0.43			0.5	66.0	33.0		33	1484
	0.5	68.4	67.8	0.43			0.6	66.0	39.6		40	1781
	1	73	72.6	0.45			0.4	132.0	52.8		53	2374
	1	72.4	72.1	0.44			0.3	132.0	39.6		40	1780
GFT Pervaporation												
hydrophobic inside	0.5	70	69.7	0.71			0.3	66.0	19.8		20	890
4/17/97	0.25	70.2	69.8	0.68			0.4	33.0	13.2		13	594
	0.25	70.1	69.8	0.69			0.3	33.0	9.9		10	445
hyrophillic inside	0.5	70.2	69.6	0.67			0.6	66.0	39.6		40	1781
	0.25	70.5	69.9	0.67			0.6	33.0	19.8		20	890
	1	70.7	70.5	0.67			0.2	132.0	26.4		26	1187
GORE TEX X11475	1	99.3	98.7	0.09			0.6	131.4	78.9		79	3547
50% POROSITY	0.5	99.5	98.7	0.09			0.8	65.7	52.6		53	2364
350 MIN H2O PRESS	0.5	99.6	98.8	0.088			0.8	65.7	52.6		53	2364
	0.25	98.8	97.7	0.083			1.1	32.9	36.2		36	1626
	0.25	99	97.8	0.084			1.2	32.9	39.4		39	1774
	1	100.2	99.8	0.089			0.4	131.4	52.6		53	2364
	2	100.4	100.3	0.092			0.1	262.8	26.3		26	1182
	0.25	98.9	97.6	0.092			1.3	32.9	42.7		43	1921
					10	50				29		
Pall HUM 10												
TAGOCHI	0.25	71.5	67.1	1.1	7	7	4.4	33.0	145.2	144	144	6496
8/21/97	0.25	71.1	67.1	5	8.2	10	4	33.0	132.0	118	125	5618
	0.5	71	68.7	1.1	7	7	2.3	66.0	151.8	144	148	6644
	0.5	71	69	5	7	8	2	66.0	132.0	126	129	5795
	0.75	71.1	69.8	2.3	15	13.5	1.3	99.0	128.7	160	144	6484
	0.25	116	106.3	1	6	7	9.7	32.8	318.0	123	221	9920
	0.25	117.4	110	5.5	7	6	7.4	32.8	242.5	168	205	9221
	0.5	119.2	114.7	1	9	5.5	4.5	65.5	294.7	235	265	11913
	0.5	118.8	115.2	5.1	15	10	3.6	65.5	235.7	216	226	10147
	0.75	119.4	116.6	1.6	8	5	2.8	98.2	275.0	230	252	11352
	0.75	119.9	117.7	5.3	9	6	2.2	98.2	216.0	216	216	9703
Millipore VSWP	0.25	71.2	65	0.35			6.2	33.0	204.6		102	4602
0.025um phillic	0.25	71.6	65.2	0.35	12	7.583333	6.4	33.0	211.2	227	219	9863
	0.25	75.1	67.8	0.63	21	10	7.3	33.0	240.9	302	271	12201
	0.25	75.3	68	0.63			7.3	33.0	240.9		120	5416
	0.125	75	66.2	0.63	12	10	8.8	16.5	145.2	172	159	7142
	0.5	75.2	70	0.53	29	10	5.2	66.0	343.1	417	380	17084

Appendix (Cont.)

WME TEST DATA RESULTS

MEMBRANE DESCRIPTION	<===== ======= RAW DATA ====== ===> WATER FLOW RATE LPM	WATER INLET TEMP F	WATER OUTLET TEMP F	TEST PRESS TORR	WATER USED ML	TIME MIN	TEMP DIFF F	WEIGHT FLOW water Lb/Hr	HEAT FLOW mcdT Btu/Hr	water HEAT vhv Btu/Hr	Average Calculated Heat BTU/Hr	Average Specific Flux Btu/Hr/Ft2
Millipore VVLP	0.5	75.6	71.8	0.36	18	10	3.8	66.0	250.7	259	255	11453
.1um hydrophillic	0.25	74.2	68.8	0.28	13.5	10	5.4	33.0	178.2	194	186	8368
	0.125	73.7	66	0.25	10	10	7.7	16.5	127.1	144	135	6088
FPI Separations	0.5	70.2	69.2	0.18	6	14	1	66.0	66.0	62	64	2869
UMD-030-PES	0.25	70.4	68.7	0.18	3.5	10	1.7	33.0	56.1	50	53	2392
Polyethersulfone	0.125	70.7	68.4	0.17	3.5	11	2.3	16.5	38.0	46	42	1881
UMD-030-PAN	0.5	70.3	66.8	0.36	17.5	9	3.5	66.0	231.0	279	255	11477
Polyacrylonitrite	0.25	70.6	65.2	0.31	11	8.5	5.4	33.0	178.2	186	182	8189
	0.125	70.9	64.1	0.27	9	10	6.8	16.5	112.2	129	121	5431
Millipore VSWP	0.125	70.7	65.8	0.19	6	10	4.9	16.5	80.9	86	84	3757
2 Layers	0.25	70.5	66.6	0.25	10	10.97467	3.9	33.0	128.7	131	130	5838
	0.5	70.3	67.8	0.45	13	10.63333	2.5	66.0	165.0	176	170	7661
Millipore VSWP	0.5	147.2	138.6	0.5	13	5.5	8.6	65.1	559.5	340	450	20217
Two Layers	0.25	145.4	135	0.45	13.5	5	10.4	32.6	338.6	388	363	16336
	0.125	141.2	126.2	0.43	12	5	15	16.3	244.6	345	295	13254
	0.125	40	39.4	0.16	2.5	14.5	0.6	16.5	9.9	25	17	780
	0.25	40	39.1	0.17	2	9.5	0.9	33.1	29.8	30	30	1350
	0.5	40	39.2	0.18	4	10.5	0.8	66.2	52.9	55	54	2421
	0.125	142.4	125.3	0.63	20	8.345667	17.1	16.3	278.8	344	312	14012
	0.25	144.5	134.3	0.63	25	9.450667	10.2	32.6	332.1	380	356	16015
	0.5	145.6	139	0.6	25	8.216667	6.6	65.1	429.5	437	433	19487
Cellgard 2500	0.125	42.4	42.1	0.14	1	16.5	0.3	16.5	5	9.0	7.0	307
	0.25	41.6	41.2	0.14	2	27	0.4	33.1	13.2	11.0	12.0	537
	0.5	41.2	41	0.15	3	21	0.2	66.2	13.2	21.0	17.0	759
	0.125	70.6	68.5	0.16	2.5	13	2.1	16.5	34.7	28.0	31.0	1401
	0.25	70.4	69.2	0.16	3.5	15	1.2	33	39.6	34.0	37.0	1644
	0.5	70.5	69.8	0.16	3.5	13	0.7	66	46.2	39.0	42.0	1909
	0.125	138.1	129.6	0.34	8.7	8.5	8.5	16.3	138.6	147.0	143.0	6423
	0.25	139.6	133.9	0.33	10	8	5.7	32.6	185.7	180.0	183.0	8215
	0.5	140.3	137	0.31	28	21	3.3	65.1	214.9	192.0	203.0	9141

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1997

3. REPORT TYPE AND DATES COVERED
Internal Report July 97-Sept. 97

4. TITLE AND SUBTITLE
Membrane Based Thermal Control Development
Interim Report

5. FUNDING NUMBERS

6. AUTHORS
Karen Murdoch

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Hamilton Standard Space Systems International
One Hamilton Road
Windsor Locks, Ct 06096

8. PERFORMING ORGANIZATION REPORT NUMBER
BD 97-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Goddard

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES
NONE

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Standard Industry Practice

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

See Attached

14. SUBJECT TERMS (keywords)
Membrane, thermal control, evaporation

15. NUMBER OF PAGES
TBD

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	